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GenCade Application at Onslow Bay, North Carolina

by Ashley E. Frey, Sophie Munger, Greg L. Williams, Michael J. Wutkowski, and Kevin B. Conner

PURPOSE: This Coastal and Hydraulics Engineering Technical Note (CHETN) describes the setup and results of a regional sediment transport analysis of Onslow Bay, North Carolina, performed using GenCade Version 1. GenCade is a regional shoreline and inlet sand-sharing model capable of evaluating engineering activities (dredging, mining, beach nourishment, structural alternatives) over years to centuries, incorporating cumulative impacts of multiple projects within large coastal systems.

INTRODUCTION: The U.S. Army Engineer District, Wilmington, requested that the Coastal Inlets Research Program (CIRP) and the Regional Sediment Management (RSM) Program apply the shoreline change and sand transport model, GenCade, to Onslow Bay to improve understanding of the regional sediment system and provide information for a sediment budget effort. GenCade is a newly developed model that combines the project-scale, engineering design-level calculations of GENESIS (Hanson and Kraus 1989) with the regional-scale, planning level calculations of Cascade (Larson et al. 2003, Connell and Kraus 2006). Inlets, inlet shoals, dredging, beach fills, bypassing, and coastal structures such as seawalls, groins, and breakwaters are represented in the model. GenCade was officially released in April 2012 following a period of extensive testing by numerous beta-users and is run in the Surface-Water Modeling System (SMS) 11.1 with georeferencing capabilities. GenCade was developed by the CIRP and the RSM Program. Additional information on GenCade including model theory, a user's guide, idealized cases, and applications may be found in Frey et al. (2012). The release version of GenCade was applied to the Onslow Bay region to help determine longshore sand transport direction and magnitude. This CHETN presents modeling results from the validation simulation (1997-2004) and from a longer period simulation (1980-1999) performed to provide a better understanding of the complex coastal processes of the region and the impact of engineering activities.

OVERVIEW: Onslow Bay is a crescentic series of barrier islands covering more than 100 miles of beaches between Cape Lookout and Cape Fear. The narrow barrier islands are separated by 11 inlets, most of which are unstructured and migrating. Understanding the dynamic nature of inlets and barrier islands, the state of North Carolina adopted a strict regulation against the use of erosion control strategies including hard structures (Division of Coastal Management (DCM) 2012). However, a new law was passed in 2011 which authorized permitting and construction of terminal groins at inlets (Rudolph 2011). Since the hard structure ban spanned several decades, few structures are present along the Onslow Bay shoreline. The only structured inlet is Masonboro Inlet which is located adjacent to Wrightsville Beach and Masonboro Island and consists of a north weir jetty and south jetty. Table 1 summarizes the history of structures in the region.

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Table 1. Chronology of coastal structures in Onslow Bay region.

Date	Location	Activity	Reference
1952	Carolina Beach Inlet	Inlet opened artificially	Cleary and Marden 2004
1966	Masonboro Inlet	Northern weir jetty constructed	Cleary and Marden 2004
1970s	Carolina Beach	Seawall constructed	Jarrett and Hemsley 1988
1970	Ft. Macon State Park	Terminal groin constructed	Walker et al. 2010
	Ft. Macon State Park	Groin constructed	(Viewed during site visit)
1981	Masonboro Inlet	South jetty constructed	Cleary and Marden 2004
1996	Ft. Fisher	Revetment constructed	Dennis 2006
1998	Old Topsail Inlet	Inlet closed	Cleary and Marden 2004
2002	Mason Inlet	Inlet relocated	Erickson et al. 2003

There are many developed barrier islands in this region including Bogue Banks in northern Onslow Bay, Topsail Island in central Onslow Bay, and Figure Eight Island, Wrightsville Beach, Kure Beach, and Carolina Beach in southern Onslow Bay. Many of these barrier islands have experienced shoreline erosion, including Wrightsville Beach and Carolina Beach which have been nourished frequently for more than 50 years, and Kure Beach, which began beach nourishment cycles in 1997 (USACE 2000). Beaches along the eastern end near Bogue Banks also suffered from chronic erosion and have been renourished five times since 1978 (USACE 2001). There are several undeveloped barrier islands primarily located in the central region of Onslow Bay. Onslow Beach, located to the northeast of New River Inlet, is used for military activity. There is very little literature on shorelines, transport rates, or wave activity in the region where the undeveloped islands are located. Most of the engineering activity including beach fills and dredging centers on Bogue Banks and Beaufort Inlet in northern Onslow Bay or the stretch from Wrightsville Beach to Kure Beach in southern Onslow Bay. Figure 1 shows an image of the region with all of the inlets and islands labeled.

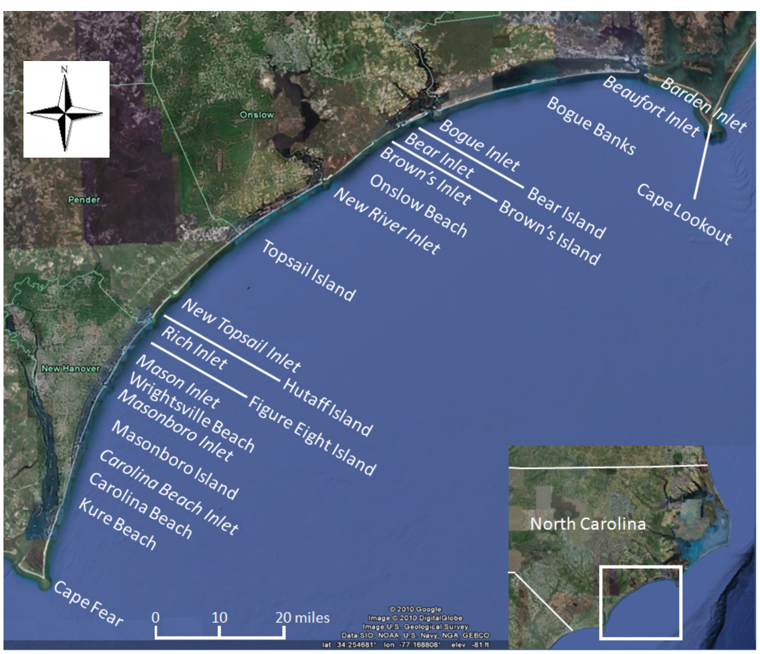

Figure 1. Onslow Bay, NC.

The recently released GenCade V1 was applied to the region beginning west of Barden Inlet and extending past Kure Beach to about two miles north of Cape Fear. Three grids were used to cover the domain to adequately represent the curvature of the shoreline. A primary grid covered most of the bay while two secondary grids extended east and west of the primary grid. The model was validated using the 1997 and 2004 shorelines. A second GenCade simulation represented the years from 1980 to 1999. This longer simulation determined longshore sand transport rates in Onslow Bay.

SETUP AND PROCEDURE: Initially, only one GenCade grid was developed to represent the project area; however, it was determined that a single grid would not accurately represent the entire Onslow Bay since shoreline angles greater than 45 deg relative to the grid angle may lead to instabilities and structure distortion and a model that cannot be properly validated. Thus, three separate GenCade grids were created to represent the shoreline change and longshore transport rates for the entire extent of Onslow Bay. By creating three separate grids, the computational axis was nearly parallel to the shoreline for each grid.

Table 2 summarizes details of the grids. The primary grid was created in central Onslow Bay. Two secondary grids overlap each end of the primary grid to ensure sufficient overlap and translation of model boundary conditions. Each overlap area extends several miles and includes at least one inlet. Figure 2 illustrates the relative alignment of the three grids. Wave gauges used for the project are shown (red, circular symbols) along with their wave roses. The three grids have a combined 2298 cells that have a constant 300 ft spacing.

Each simulation requires an initial shoreline, a regional contour, a time series of directional waves, and existing and equilibrium volumes of morphological features composing the ebb and flood shoals of each inlet. Other required inputs are berm height, closure depth, and the effective grain size. Beach fills and engineering structures are present in some of the grids.

In GenCade, berm height elevation and closure depth must be reported in the same tidal datum as the initial shoreline (Mean High Water [MHW]). Shoreline data were obtained from USGS and consist of a MHW shoreline derived from the 1997 lidar survey. The regional contour was formed by filtering out spatial variations smaller than 2.25 miles along the 1997 shoreline with a zero-phase digital filter. Wave characteristics for the short term and long term GenCade simulations were taken from the Wave Information Study (WIS)[1] which provides a 20 year long continuous record from 1980 to 1999 output hourly. Data were collected from six wave gauges in the Onslow Bay region (Figure 2). WIS Stations 63276, 63279, 63292 and 63298 were used for the primary grid; WIS Stations 63274, 63276, and 63279 were used for the Beaufort secondary grid; and WIS Stations 63298 and 63304 were represented in the Masonboro secondary grid. Stations are located at water depths ranging from 53 to 73 ft MHW. The 1980-1999 simulation used the entire 20 year record. Since wave information was unavailable for part of the 1997-2004 simulation, representative waves for the missing years of 2000-2004 were used. The average closure depth for the bay was determined to be -26.5 ft MHW, the berm height was 4.5 ft MHW, and the mean grain size was 0.17 mm (USACE 2001).

[1] http://frf.usace.army.mil/wis2010/wis.shtml

Table 2. Summary of grids developed for Onslow Bay.					
Grid	**Location**	**Extent**	**Length, miles**	**Orientation, clockwise from North**	**Notes**
Primary	Central Onslow Bay	10 miles east of Bogue Inlet west to north jetty at Masonboro Inlet	61	240°	Includes 7 inlets (Bogue Inlet to Mason Inlet)
Secondary – East	Beaufort	1.6 miles west of Barden Inlet to 2.7 miles past Bogue Inlet	34.3	260°	Overlaps with primary grid at Bogue Inlet
Secondary – West	Masonboro	1 mile south of New Topsail Inlet to 2 mile north of Cape Fear	36.1	217.5°	Includes four southern-most inlets, Wrightsville Beach and Carolina Beach; overlaps Primary grid at Rich and Mason Inlets

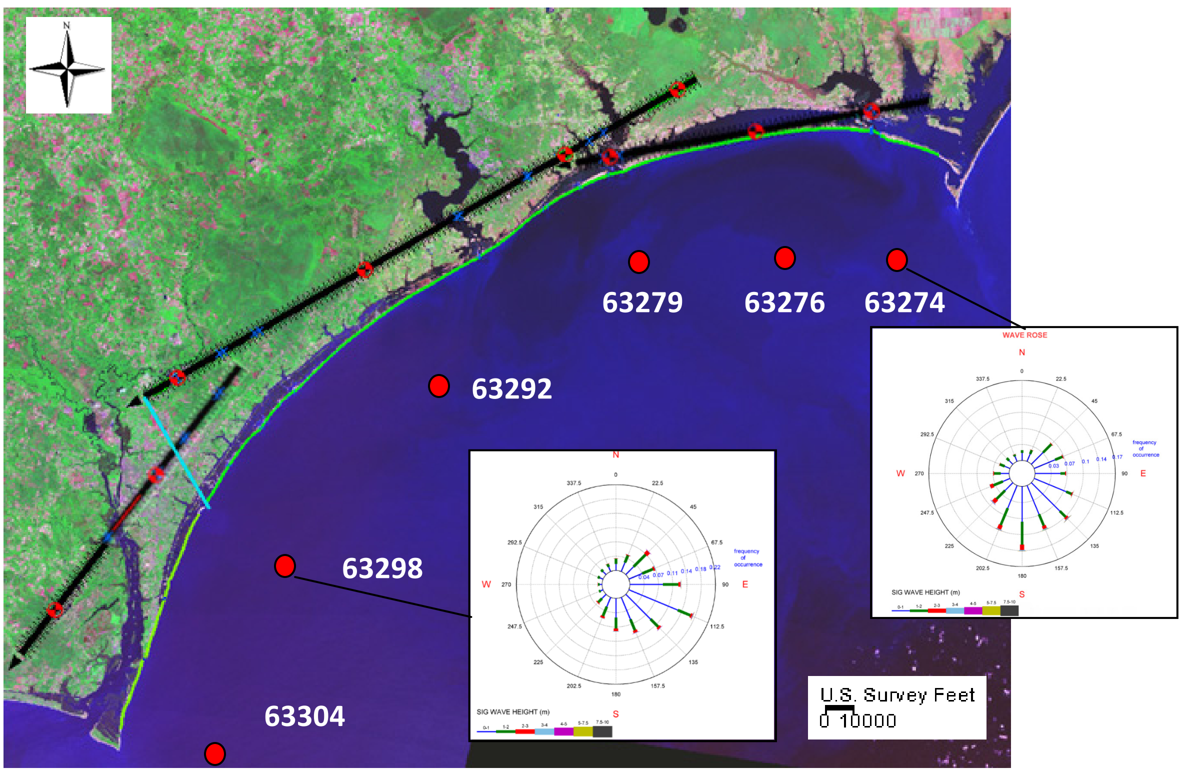

Figure 2. Primary Grid in Center, Secondary Grids in upper right and lower left. WIS wave stations used as input (red circles) and wave roses for stations 63274 and 63298 are also presented.

A simplified version of the Inlet Reservoir Model (Kraus 2002) exists within GenCade. The total shoal volumes for inlets are divided into six morphological features: the left/right attachment bars, the left/right bypassing bars, the ebb shoal proper, and the flood shoal. The proportions of these features were determined using bathymetric surveys when available or visually from historical aerial photographs when not available.

Engineering activities such as beach fills and dredging were compiled from literature (Jarrett and Hemsley 1988; USACE 2000; USACE 2001; Olsen 2006) and input in GenCade for the validation period from 1997-2004. Table 3 describes the beach fill locations, date, and added berm width (from beach fill volumes) for each event during the 1997-2004 simulation. The same process was used for the 1980-1999 simulation, but the tables are not shown here to conserve space.

Table 3. Beach Fill Locations in Onslow Bay.

Beach Location	Date	Added Berm width (ft)
Fort Macon	2002	37
Pine Knoll Shores	2002	40
Indian Beach	2002	57
Emerald Isle (phase 2)	2003	51
Figure Eight Island	1999	39
Figure Eight Island	2002	48
Figure Eight Island	2003	17
Wrightsville Beach	1998	95
Wrightsville Beach	2002	68
Masonboro Island	1998	40
Masonboro Island	2002	37
Carolina Beach	1998	95
Carolina Beach	2001	78
Carolina Beach	2004	53
Kure Beach	1997	160
Kure Beach	1998	58
Kure Beach	2004	9

Dredging volumes at Beaufort Inlet for the 1997-2004 run were obtained from Olsen Associates (2006). The data are based on volumes published in the USACE Section 111 Report (2001) which were revised and updated with recent dredge records provided by Olsen Associates.

Inspection of the present shoaling patterns indicated that sand removed by maintenance dredging mostly came from the west and east bypassing bars. Previous analysis of the shoaling characteristics of Beaufort Inlet found between 65 percent and 70 percent of the shoaling occurs on the west side of the channel (USACE 1976; USACE 1990). To reflect this distribution, 70 percent of the dredged volume was removed from the west bypassing bar and the remaining 30 percent from the east bypassing bar. The volumes shown in Table 4 represent the combined volume dredged from the east and west bypassing bars.

Sediment traps are located in the throats of Masonboro Inlet and Carolina Beach Inlet (USACE 2000). The sediment trap in Masonboro Inlet is used as a source of nourishment material for Wrightsville Beach and Masonboro Island. Sand has been transferred from Masonboro Inlet to the adjacent beaches every 3-4 years since 1981. The sediment trap in the throat of Carolina Beach Inlet has nourished Carolina Beach since 1981. Additionally, Carolina Beach Inlet is very shallow, so dredging is conducted every year to maintain the authorized depth of 8 ft (USACE 2000). Table 5 shows the volume of sand dredged from the inlets in the southern portion of Onslow Bay.

Table 4. Dredging at Beaufort Inlet.	
Year	**Volume (yd³)**
1997	267,656
1998	2,240,267
1999	1,040,919
2000	1,701,659
2001	834,757
2002	861,074
2003	1,144,987
2004	813,119
Yearly Average	1,113,041

Table 5. Dredging Events in Southern Onslow Bay (1997-2004)		
Inlet	**Year**	**Volume (yd³)**
Rich Inlet	1999	200,000
Rich Inlet	2002	250,286
Rich Inlet	2003	90,000
Masonboro Inlet	1998	1,672,227
Masonboro Inlet	2002	1,302,517
Carolina Beach Inlet	1997	50,526
Carolina Beach Inlet	1998	1,525,559
Carolina Beach Inlet	1999	188,054
Carolina Beach Inlet	2000	188,054
Carolina Beach Inlet	2001	1,188,054
Carolina Beach Inlet	2002	188,054
Carolina Beach Inlet	2003	188,054
Carolina Beach Inlet	2004	1,392,700

RESULTS AND DISCUSSION: Most inlets in Onslow Bay are not stabilized with jetties, so the beaches are free to respond to morphologic fluctuations in the inlets in addition to seasonal and long-term changes associated with wave-induced longshore sand transport. Because data and regional transport studies at Onslow Bay are very limited, shoreline change data were used to calibrate the model. Calibration is achieved by varying the K1 and K2 coefficients from the transport equations following the procedure described in Frey et al. (2012). It was determined that a K1 of 0.6 and a K2 of 0.4 provided the best domain-wide agreement. The weir jetty of Masonboro Inlet was simulated by increasing the porosity of the north jetty. Calibration simulations from the GenCade model were compared to results of previous studies at Beaufort Inlet (USACE 2001; Olsen 2006), post dredging monitoring surveys at Beaufort and Masonboro Inlets, sediment trap volumes at Masonboro Inlet and Carolina Beach Inlet, and measured shorelines. The goodness-of-fit of the calculated shoreline versus the 2004 measured shoreline was assessed by calculating the root mean square error (RMSE), the bias, and the Brier skill score (BSS). The statistics are defined on the CIRP Wiki[1]. In addition, the correlation coefficient between the calculated and measured shoreline change was evaluated. Figure 3 shows the measured and calculated shoreline change obtained for each of the three grids, and Table 6 presents skill scores obtained for each grid.

[1] http://cirp.usace.army.mil/wiki/Statistics

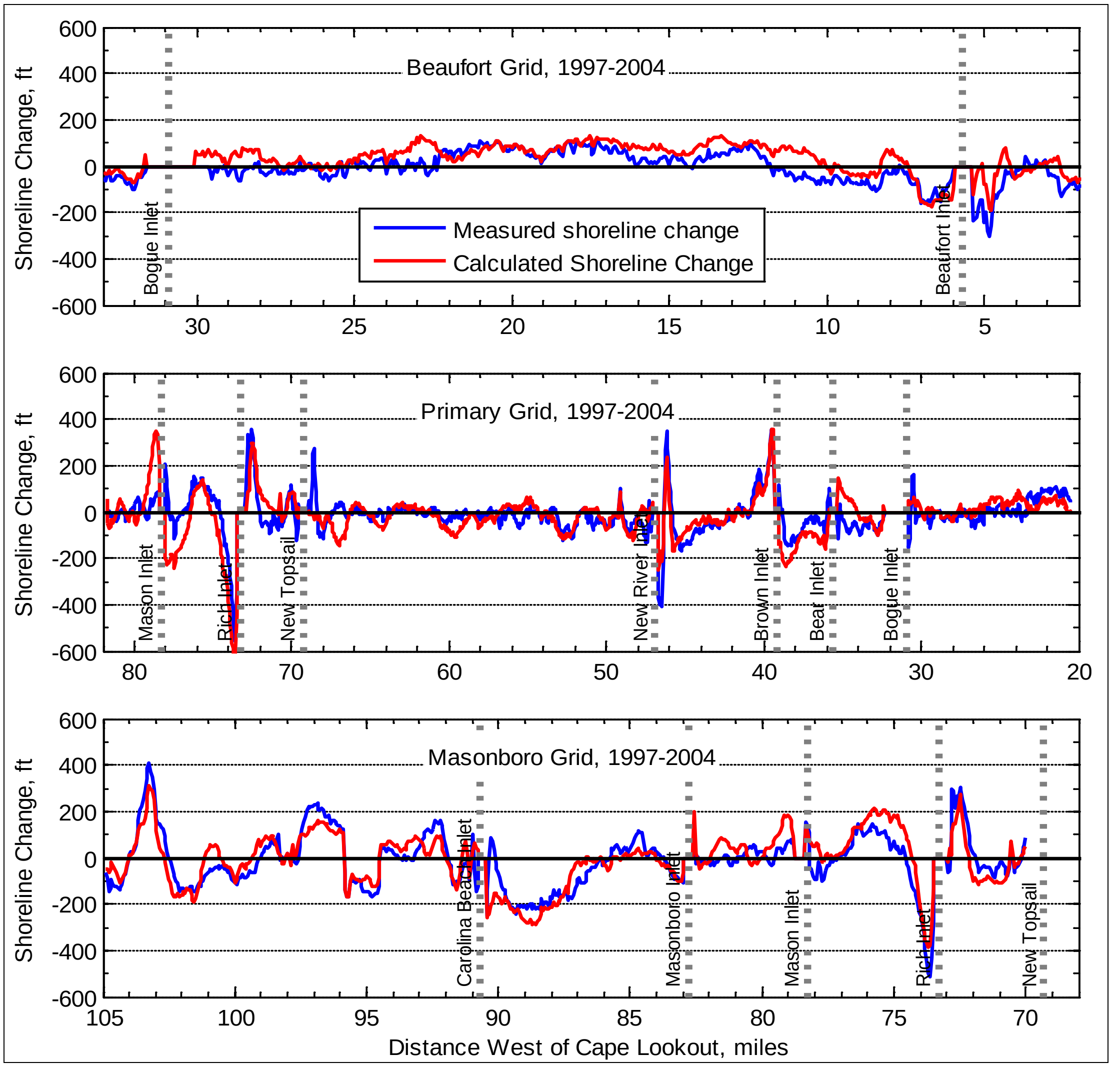

Figure 3. Calculated and measured shoreline change for the Beaufort grid, primary grid and Masonboro grid.

Table 6. Statistics and Skills Score of Validation Runs.

		Beaufort	Primary	Masonboro
Calculated Shoreline	BSS	0.63	0.37	0.71
	Bias (ft)	16.5	-6.64	6.6
	RMSE (ft)	40.5	55.6	67.0
Shoreline Change	R^2	0.83	0.70	0.84

During calibration, the calculated shoreline accreted at Masonboro Island and at Carolina Beach in the Masonboro grid. However, the 2004 measured shoreline indicated erosion along most of Masonboro Island and only slight accretion south of Carolina Beach Inlet. Although many different calibration coefficients and parameters were tested, this calculated accretion occurred in every case. Further review of the literature indicates the presence of a Pleistocene submerged headland halfway between Masonboro Inlet and Carolina Beach Inlet (Doughty 2006), which was not directly accounted for in the model. This headland locally disturbs the wave field and longshore sand transport, and the rocky bottom might also reduce sediment supply acting like a sediment sink. To account for the headland, a background erosion rate of -150 cy/hr was applied to the grid cells representing the southern half of Masonboro Island. Including this erosion rate greatly improved the 2004 calculated shoreline for the Masonboro grid.

The primary grid resulted in a lower BSS than the two other grids (Table 4). Inlets in the central portion of the bay are very dynamic (Cleary and Pilkey 1996). Phenomenon such as shoal collapse due to channel alignment fluctuation and migration of the inlet banks are not represented in GenCade and contribute to the lower skill score.

Once the model was setup and properly validated, the entire 20 year WIS hindcast was used to determine the mean direction of net transport. The 20 year simulation was executed for each of the grids and merged where overlaps between grids occurred (Figure 4). East and west transport magnitude is within +/- 100,000 cy/yr of transport calculated in a recent study completed by Olsen Associates (2006) in the Beaufort Inlet region. Figure 4 shows a net transport rate between 30,000 cy/yr and 300,000 cy/yr to the northeast for Topsail Island. Previous studies in the area calculated a net sediment transport rate of 200,000 cy/yr to the northeast and a gross sediment transport rate of 1,289,000 cy/yr (USACE 1989; USACE 2010). Jarrett (1977) completed a sediment budget from Wrightsville Beach to Kure Beach and calculated gross sediment transport rates of 1,037,000 and 1,088,000 cy/yr for Wrightsville Beach and Kure Beach, respectively. Figure 4 shows a net sand transport rate of 100,000 cy/yr to the southwest and a gross sand transport rate of about 1,000,000 cy/yr at Wrightsville Beach. The net sand transport rate was approximately 200,000 cy/yr to the southwest and the gross sand transport rate was about 1,000,000 cy/yr at Kure Beach. Results from the 20 year simulation indicate a gross mean sand transport on the order of 1 Mcy/yr consistently across all of Onslow Bay. The sand transport direction fluctuates from northeast to southwest in such a way that the net transport is generally small, less than 200,000 cy/yr, and directed to the northeast from New River Inlet to Beaufort Inlet and to the southwest for the southern half of the bay, which is consistent with literature from those with specific knowledge of the area (Cleary and Pilkey 1996; Cleary and Marden 2004).

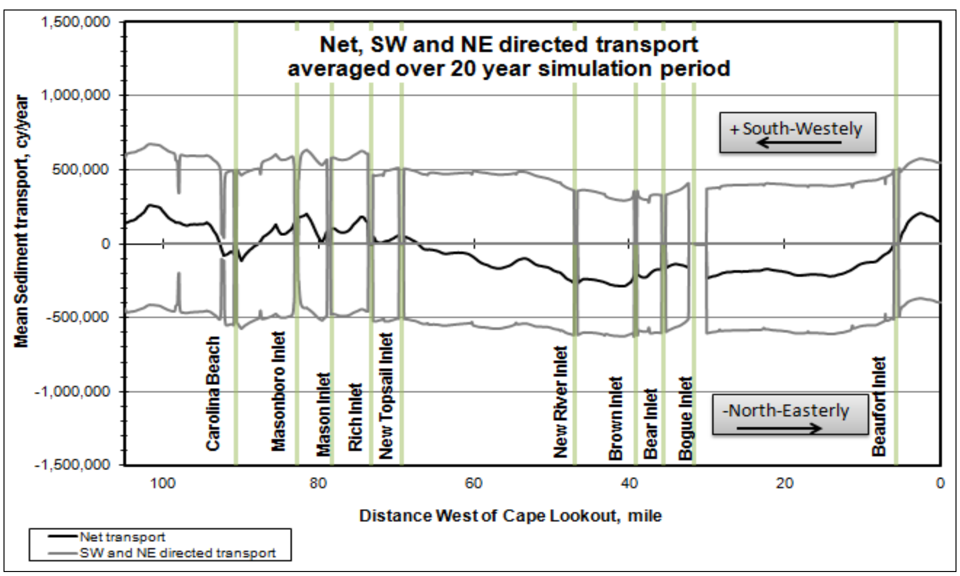

Figure 4. Net transport averaged over 20 year simulation period.

The small net transport relative to the gross indicates strong variability in the transport magnitude and direction. For the 20 years calculated, the resulting net transport direction shifts from year to year depending on wave climate. Figure 5 shows net transport averaged over 20 years as well as the maximum and minimum annual net transport envelope. For example, in the region surrounding Beaufort Inlet, the average mean net transport is approximately 0 cy/yr. However, the net transport varies from 600,000 cy/yr to the west to 400,000 cy/yr to the east, depending upon yearly fluctuations. The variability of the dominant transport is a direct result of the geometry of the Bay. Onslow Bay is facing south and southeast and is relatively sheltered by the waves coming from the northeast (Olsen 2006; Riggs et al. 2011). But, seas developed by the dominant southerly wind impact the coast directly. as seen by the wave roses in Figure 1. where a small change in incident wave angle can reverse transport direction. In addition, tropical and extratropical storms can impact the shore from the southeast or southwest, depending on storm trajectory.

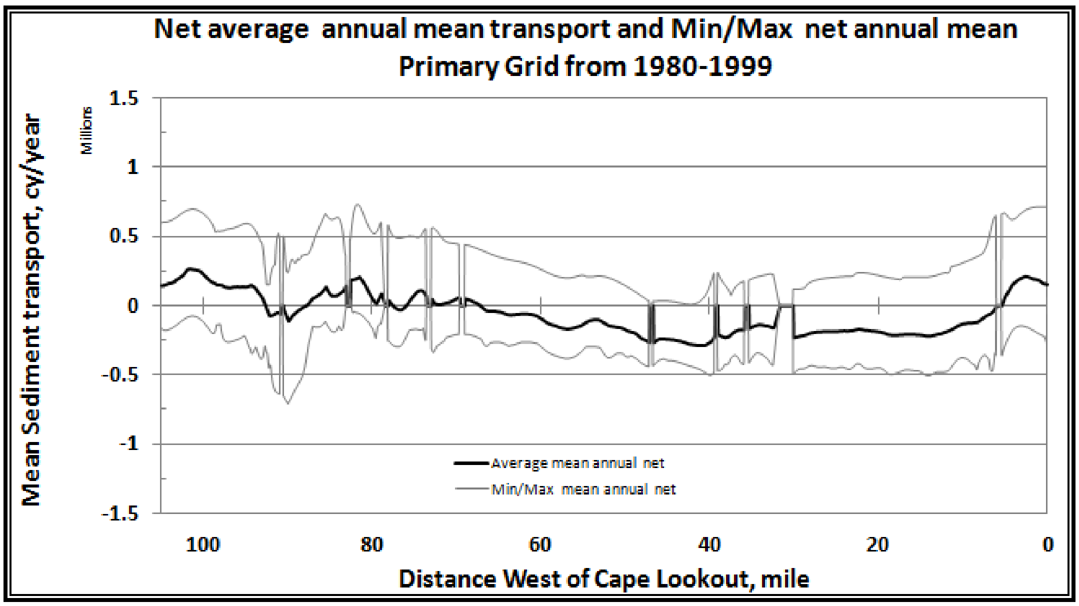

Figure 5.Net average annual and min/max net annual mean transport from 1980-1999.

CONCLUSIONS AND SUMMARY: This CHETN describes a shoreline change and sand transport application of GenCade V1 at Onslow Bay, NC. A validation case was simulated for 1997-2004 for three separate GenCade grids. Based on statistics and skills scores and a visual comparison between measured and calculated shorelines, the validation case for all three grids modeled the 2004 shoreline reasonably well. A 20-year case, based on the 20 year WIS hindcast, was also simulated to estimate longshore sand transport rates for a longer time period. GenCade predicted a gross transport of approximately 1 Mcy/yr consistently across the bay. The net transport is on the order of 200,000 cy/yr and is directed northeast from New River Inlet to Beaufort Inlet and southwest from New Topsail to Carolina Beach Inlets. The calculated sand transport direction is consistent with previous studies and with general knowledge of the area. Although this was one of the first studies to use the GenCade model, the results show that GenCade accurately calculates shoreline change and sand transport.

AVAILABILITY: The GenCade executable is available through the CIRP website under Products – GenCade, *http://cirp.usace.army.mil/products*.

POINT OF CONTACT: This CHETN was prepared as part of the Coastal Inlets Research Program (CIRP) and Regional Sediment Management Program (RSM) and was written by Ashley E. Frey (*Ashley.E.Frey@usace.army.mil*, voice: 601-634-2006) of the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), Sophie Munger (*Sophie.Munger@gmail.com*) of Blue Science Consultants, LLC and sponsored by Texas A&M University Corpus Christi, and Greg L. Williams, Michael J. Wutkowski, and Kevin B. Conner of the U.S. Army Engineer District, Wilmington. Dr. Julie Rosati, Kenneth Connell, and Rusty Permenter provided peer-review of this publication. This technical reference should be referenced as follows:

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